EUV Lithography and EUVL sources

V. Banine & R. Moors

Content

- EUV lithography: History and status
- EUV sources- historical perspective:
  - Age of choice
  - Age of Xe
  - Age of Sn
  - Age of industrialization
  - … and beyond
- Final remarks

EUV has come a long way in last 25 years

1st papers soft X-ray for lithography (LLNL, Bell Labs)

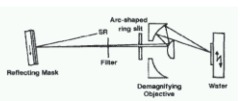
ASML start EUVL research program

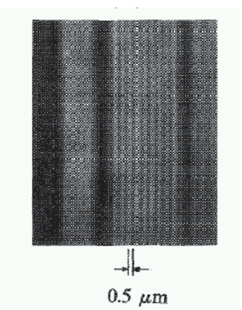
ASML ships 2 alpha tools to IMEC (Belgium) and CNSE (USA)

ASML ships pre-production tools

'85	'86	'87	'88	'89	'90	'91	'92	'93	'94	'95	'96	'97	'98	'99	'00	'01	'02	'03	'04	'05	'06	'07	'08	'09	'10	11

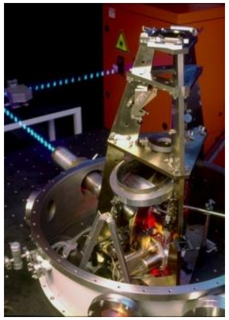
Japan:

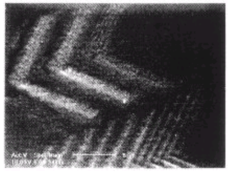




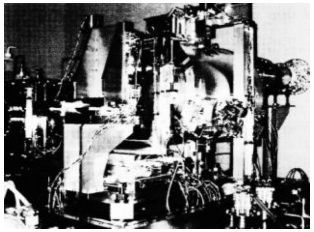
Kinoshita et al

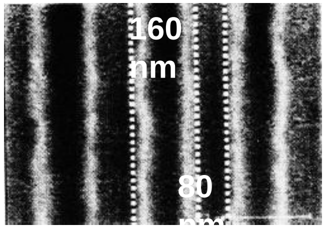
NL:



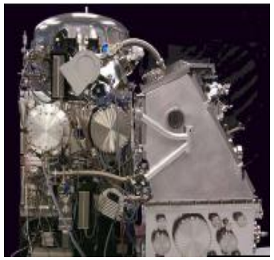


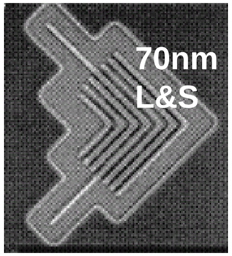
Japan:





USA:





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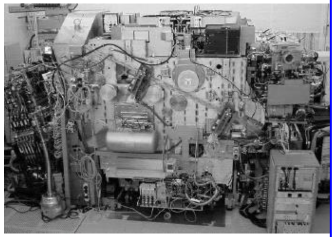
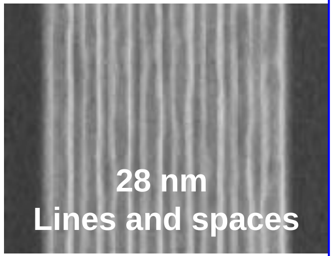
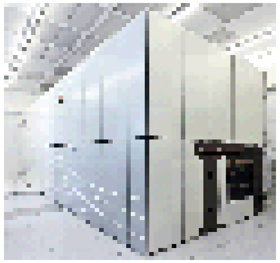
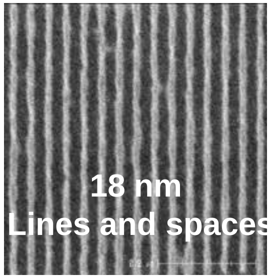




NL:





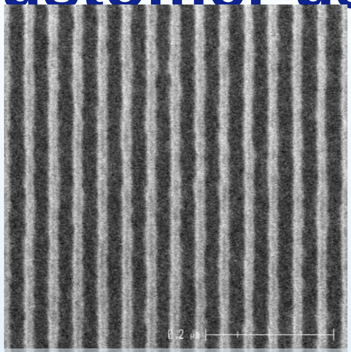
- ASML has active program since 1997.
- Currently >1000 people work on pre-production systems are shipped 2010-11.

EUV and BEUV product roadmap spans >10 years

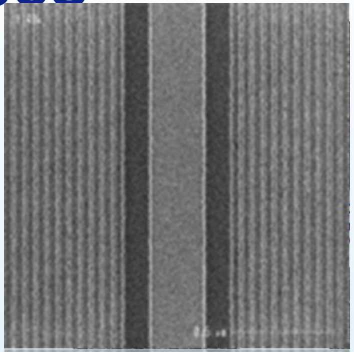
	0.25 NA		0.33 NA		*Under study* >0.40 NA	
Lens mirrors	6M	6M	6M	6M	6/8M	6/8M
Wavelength	13.5 nm	13.5 nm	13.5 nm	13.5 nm	13.5 nm	New λ
Product	**ADT**	**3100**	**3300B**	**3300C**	**3500**	**>3500**
Introduction year	**2006**	**2010**	**2012**	**2013**	**2016**	**>2018**
Resolution (hp)	32 nm	27 nm	22 nm	18 nm	11 nm	<8 nm
Sigma	0.5	0.8	0.2-0.9	OAI	flex OAI	flex OAI
Overlay (SMO)	7.0 nm	4.5 nm	3.5 nm	3.0 nm		
Throughput (wph)	4 wph	60 wph	125 wph	150 wph		

6 NXE 3100 tools are shipped

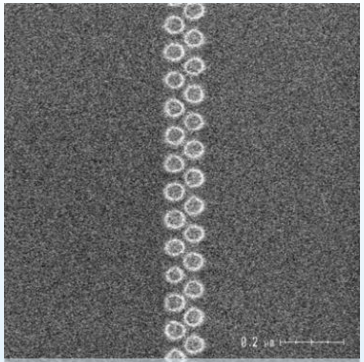
NXE:3100 imaging performance proven for customer use cases



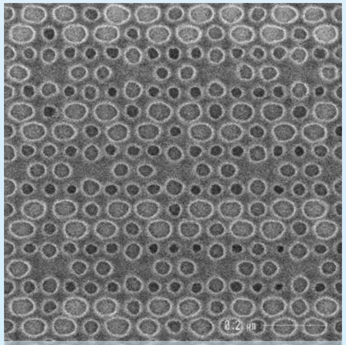
19 nm dense lines



27 nm Gate Layer Flash

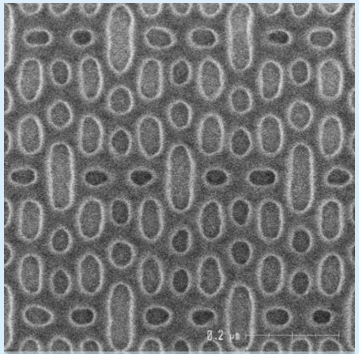


Flash staggered contact layer
Bitline pitch = 44 nm (1:1.2)
CH pitch = 74.4 nm



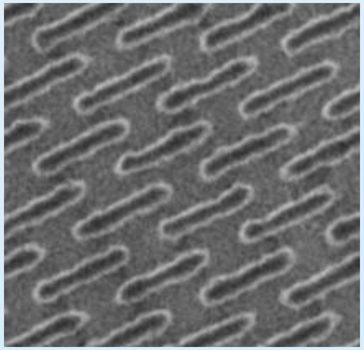
Sub 16 nm node SRAM Contact Hole

0.038µm2 bit cell-size,
hp 30/32 nm



Sub 16 nm node SRAM metal-1

0.038µm2 bit cell-size,
hp 30/32 nm



30 nm Brickwall DRAM

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NXE:3100 and source challenges

Challenges:

•To produce enough power (Plasma source)

•To protect collection optics from the debris produced by the source (Plasma sputtering and deposition)

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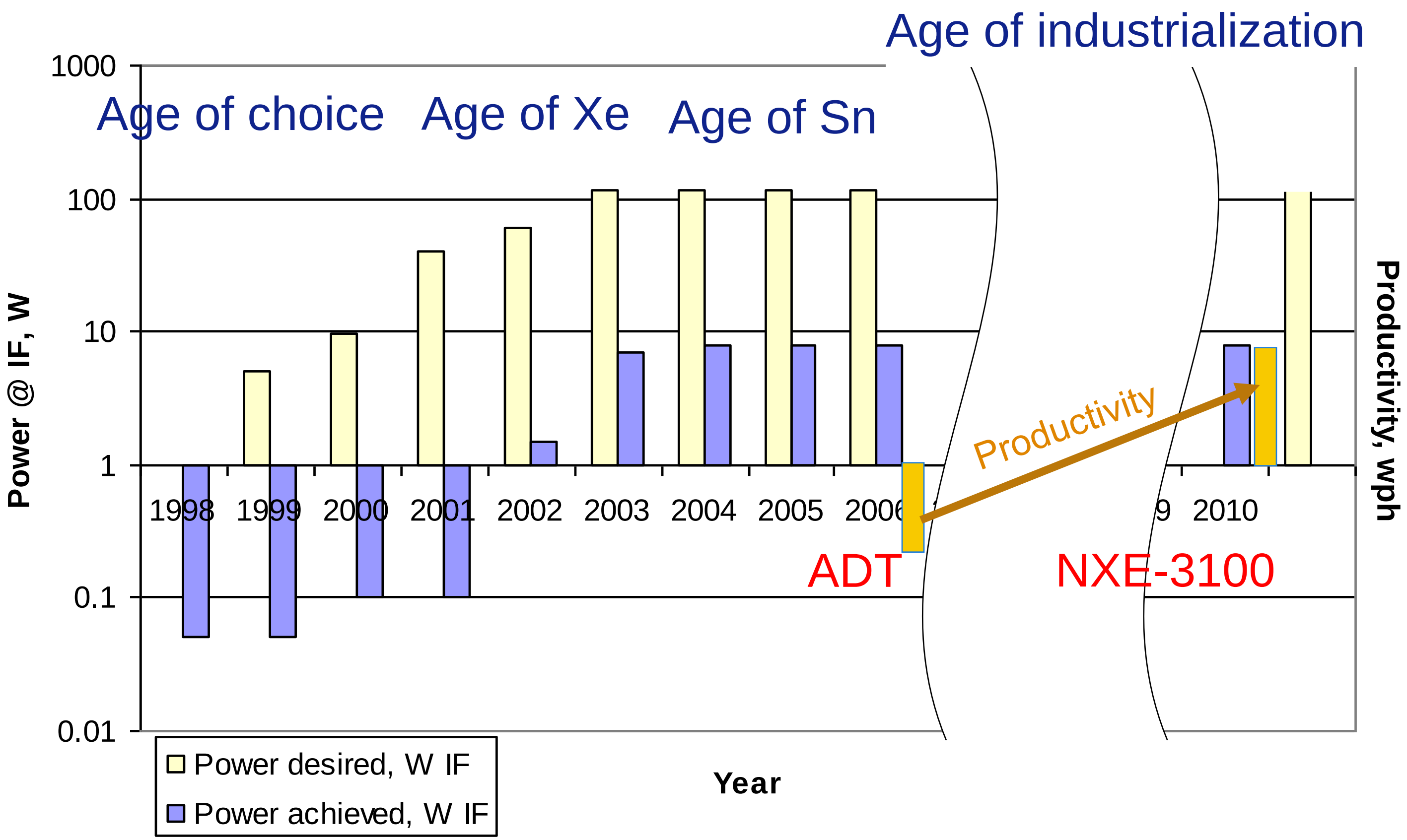
Historical perspective: Production power requirement, achieved power, productivity



Averaged and independent on supplier

Gap in productivity is being bridged,
in reliable power is still 10x to go.

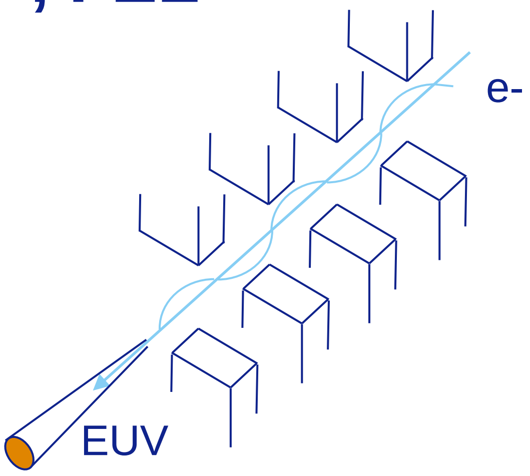
Among other configurations in age of choice:

Synchrotron wiggler, undulator , FEL

Never made it

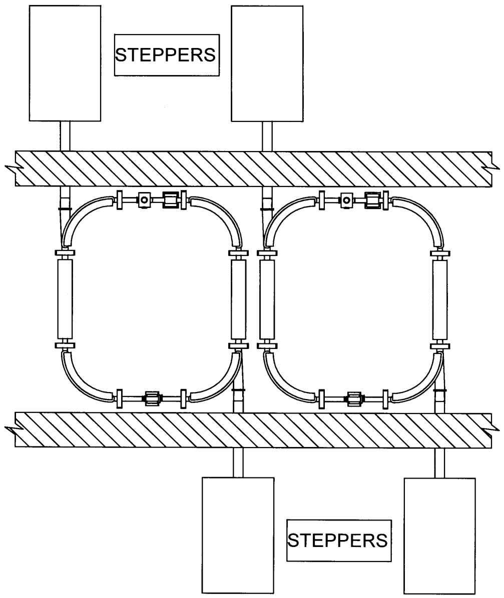
Principle:

1. Relativistic electrons traversing a periodic magnetic structure are being bent;
2. Being bent, electrons emit EUV.



Prospects before 2000:

1. No debris;
2. Good dose repeatability;
3. High maturity (1999!);
4. High uptime



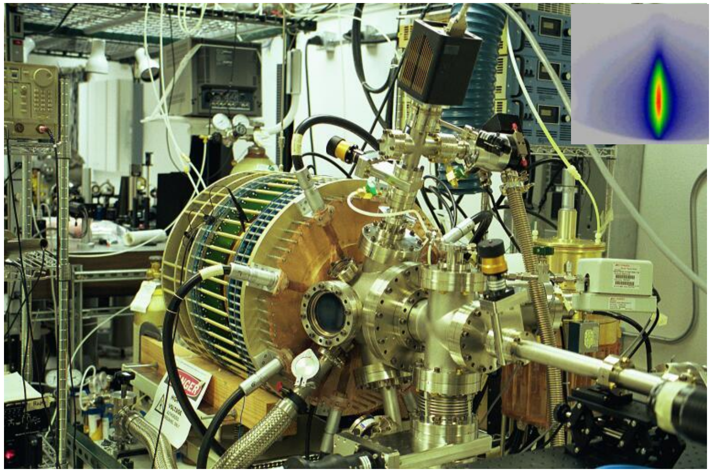
Issues:

1. High CoO;
2. Non-flexible configuration.
3. Not enough power (2005!)
4. Current update: 0.2 W with FLASH (250 m installation)

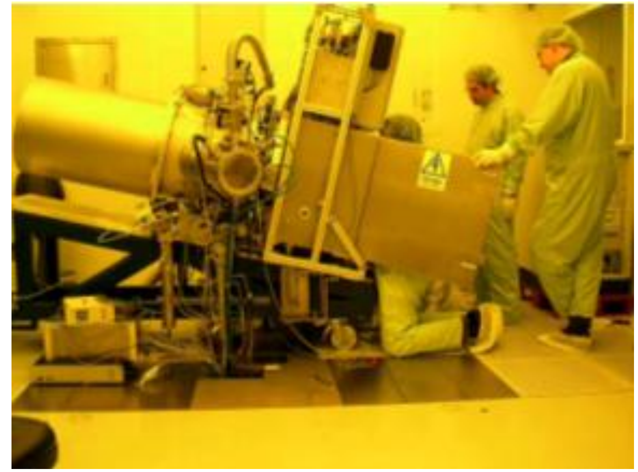
See for further reference eg: DC Ockwell et al J. Vac. Sci. Technol. B **17**, 3043 (1999)

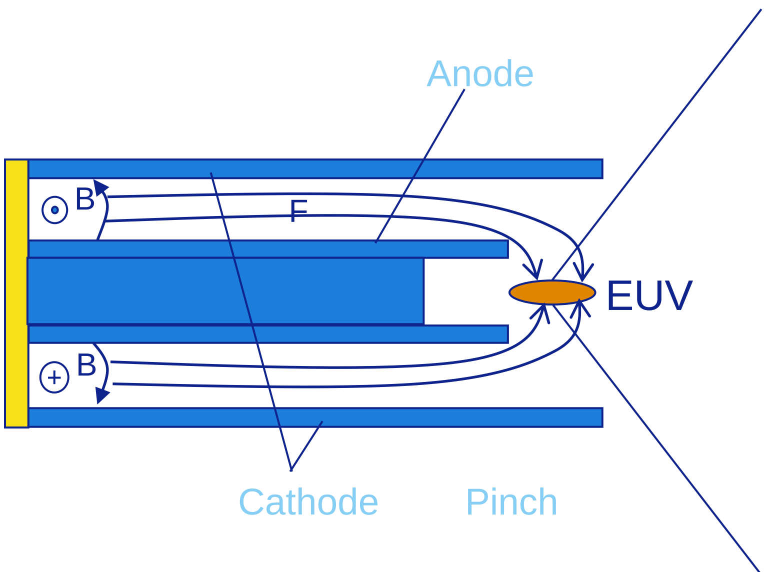
Age of Xe

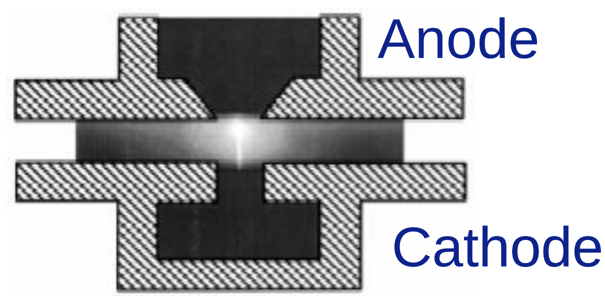
Plasma Focus of Cymer



HCT of Philips

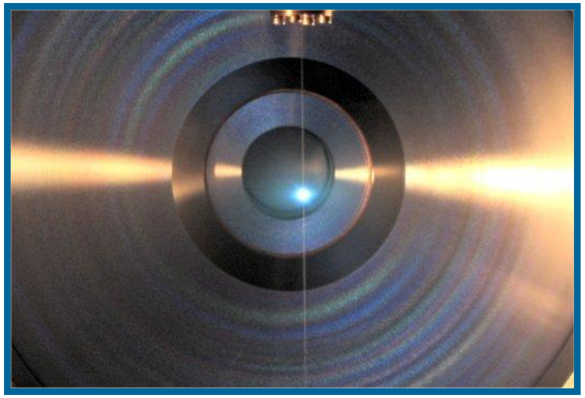


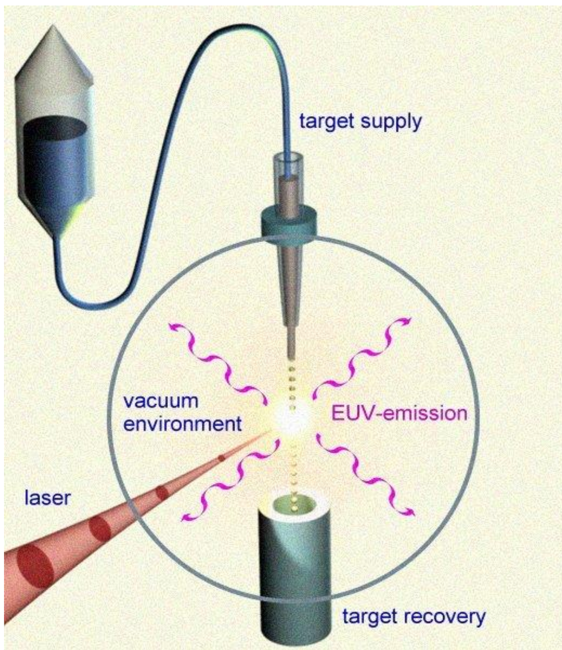




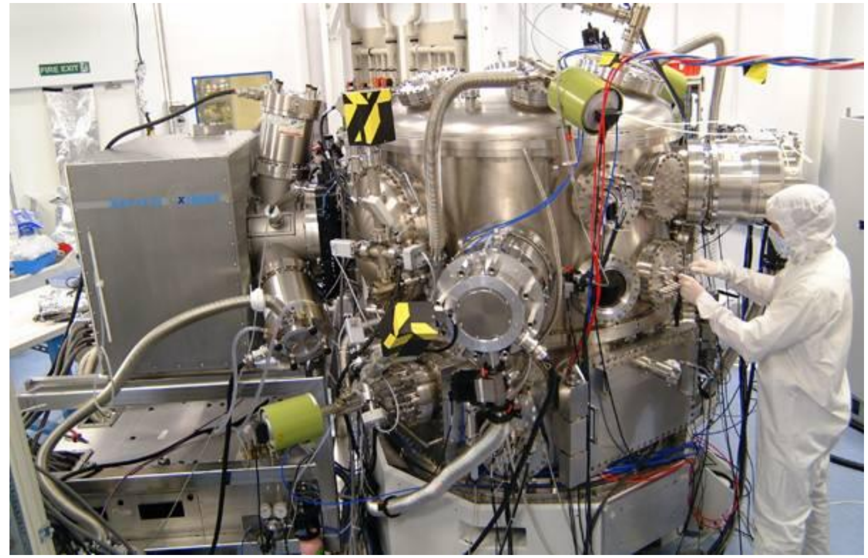
Bergmann *et al.*, Microel.eng. 57-58, 2000, pp. 71-77

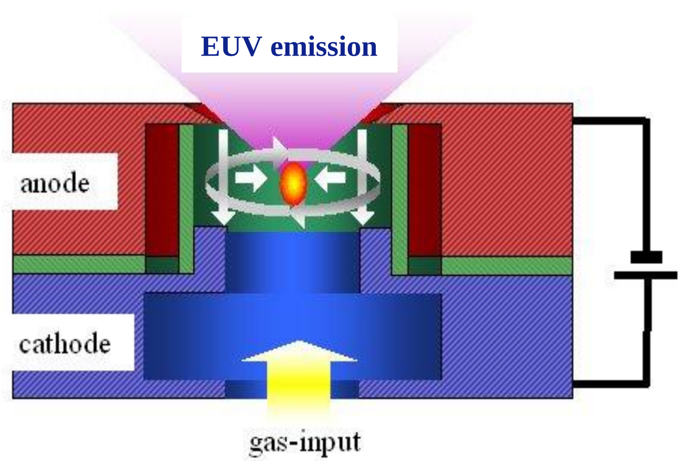
Xtreem (Lambda) LPP





Z-pinch

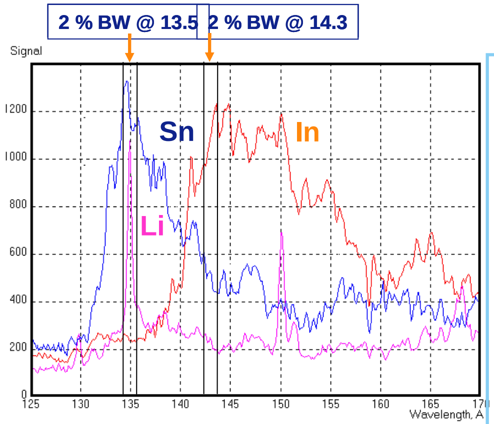




End of Xe age

- Too low conversion efficiency 0.5-1.1% (in-band in 2π)
- Not high enough projected maximum power (30-40 W @IF)
- Short lifetime of electrodes (DPP) (several hours of operation)
- Too high CoO for LPP at such CE
- Emerging alternative: Sn and Li (up to 3.5-5 % CE) and potential multiplexing (early trials at ASML-ISAN, Cymer et al)

Emerging alternative



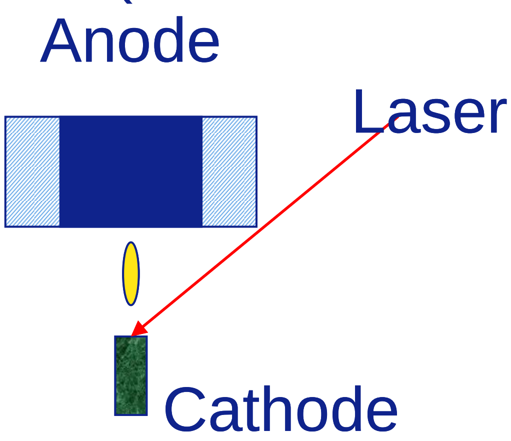
E_{in}= 3 J

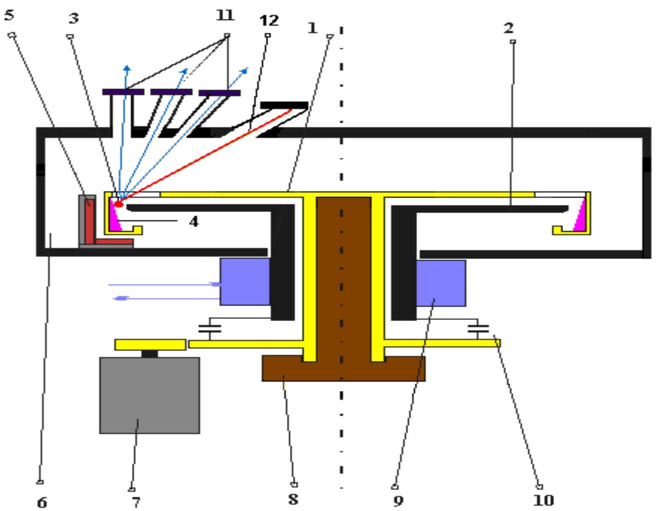
CE (2% BW, 2π):

in 13.5nm:
Li = 0.5%
Sn = 2 - 3.5 %
(best ever)
in 14.3 nm:
In = 1 %

Concern: Potentially increased debris production with respect to gaseous materials

Pseudo spark (ASML-Troitsk) 2000





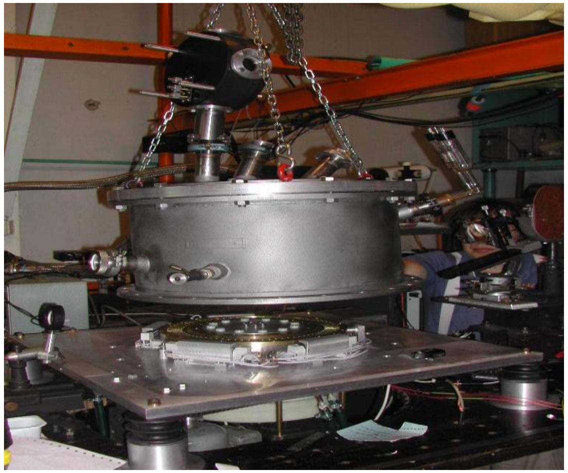
Multiplexing

Achieved:
- 2 % CE
- 100 Hz (ignition laser limited)

10 W in 2π in-band (1-2 W in IF)

Prospect:
- 2-3%
- 1000 Hz

>100 W in IF



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  - Age of Sn – the beginning
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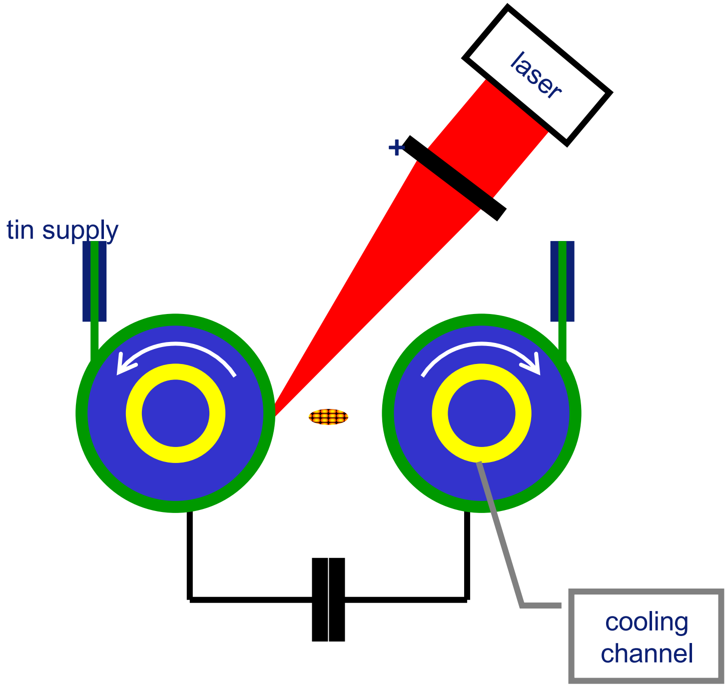
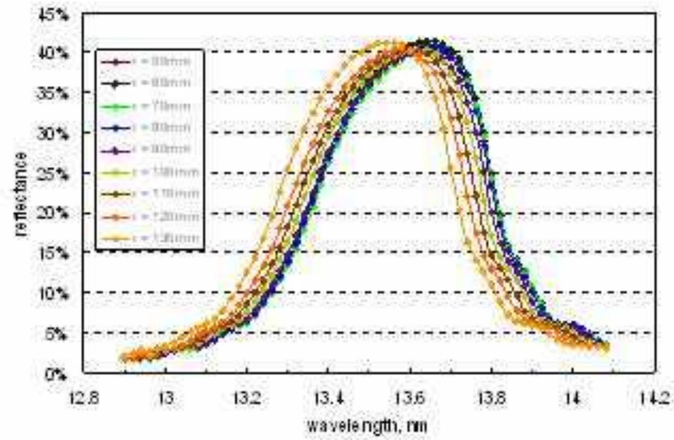
Philips' EUV Lamp: Sn-based rotating electrodes



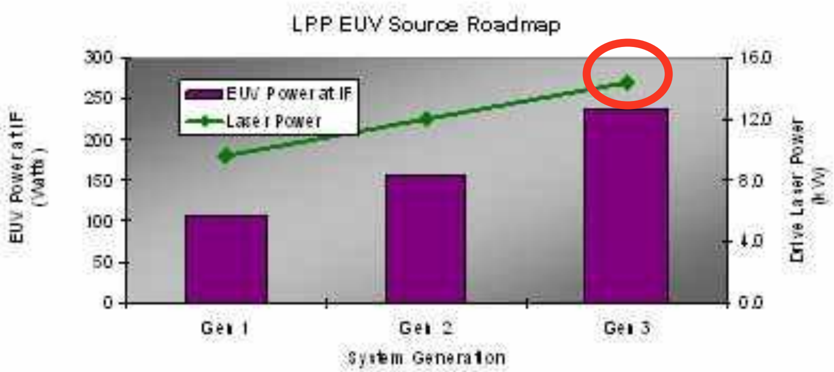
- 200W/2π continuous operation (scalable to >600W /2π)
- very small pinch (<1mm)
- >>1 bln shots electrode life
- commercial product

Development of one of the first LPP with Sn was started

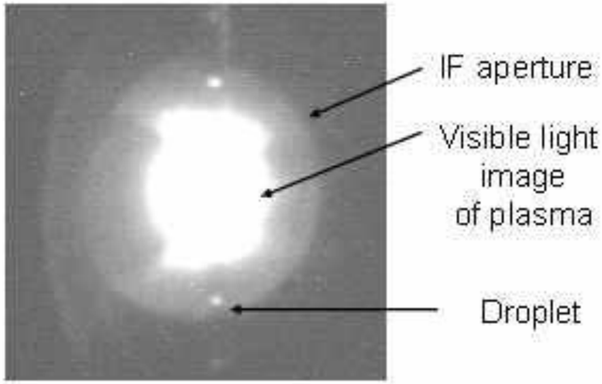
• 320mm diameter 1.6 sr collector



• First article collector, ~41% peak reflectivity



• LPP EUV Source Power at IF Roadmap



• Image of the plasma aligned with the IF aperture as seen through the collector

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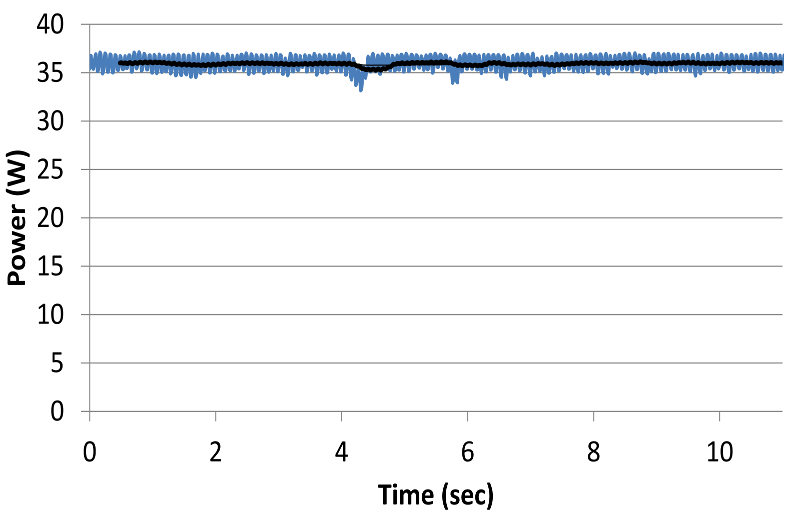
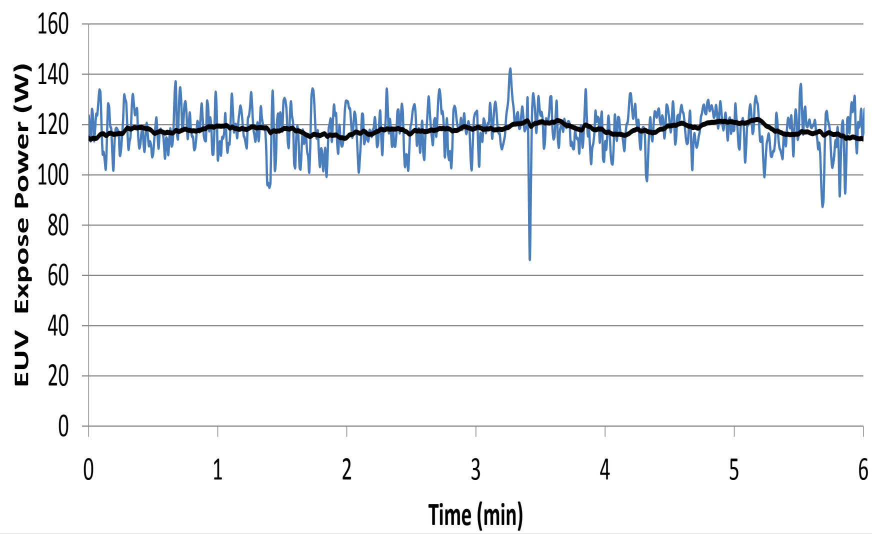
NXE Source power roadmap and LPP progress

- Expose power ~35W and 80% duty cycle
- Dose Stability <±0.5%
- Qualified and implementation according to roadmap



- Expose power >100W with Pre-Pulse
- Feasibility completed at low duty cycle, no dose control
- Full feasibility to be completed H2 '11 for implementation in H2 '12.



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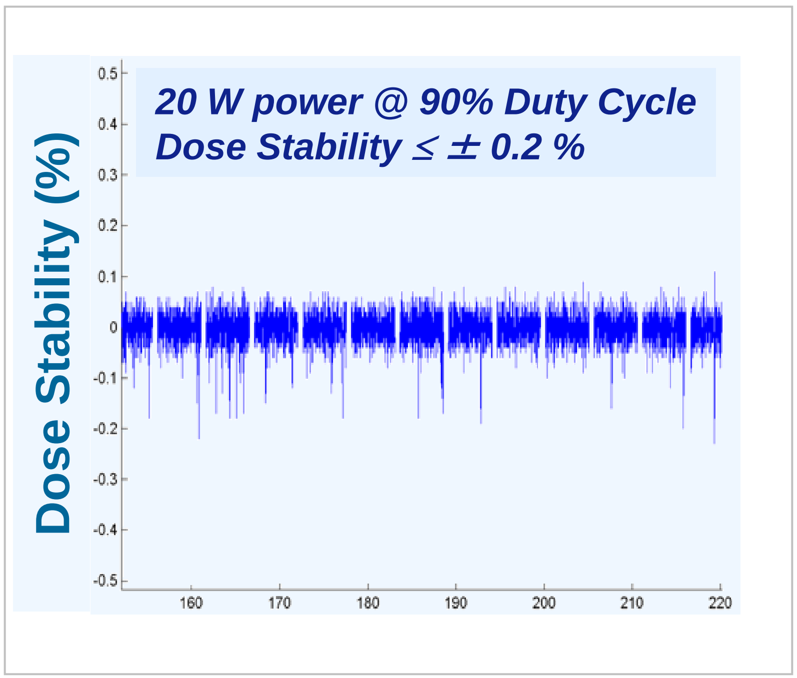
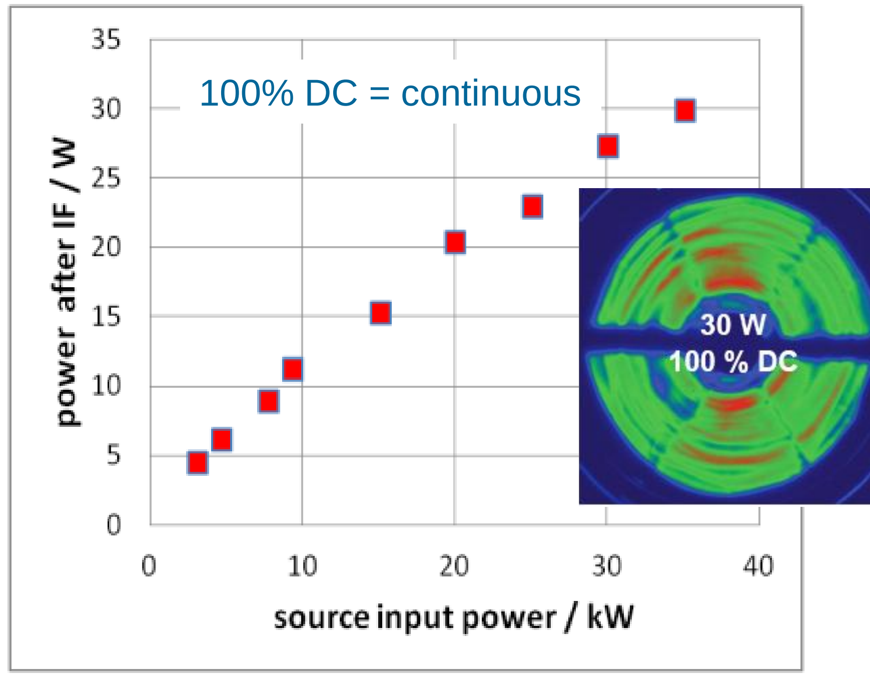
ASML

NXE Source power roadmap and LDP progress

Q3 2011	Q4 2011	Q1 2012	Q2 2012	Q3 2012	Q4 2012	
Power **<10W**						
		Power **20-50W**				
				Power **>100W**		
						>>100W

- 20 W qualified and implementation according to roadmap
- Progress beyond 20 W shown up to 30 W, 100 W feasibility to be completed H1 '12 for H2 '12 implementation.





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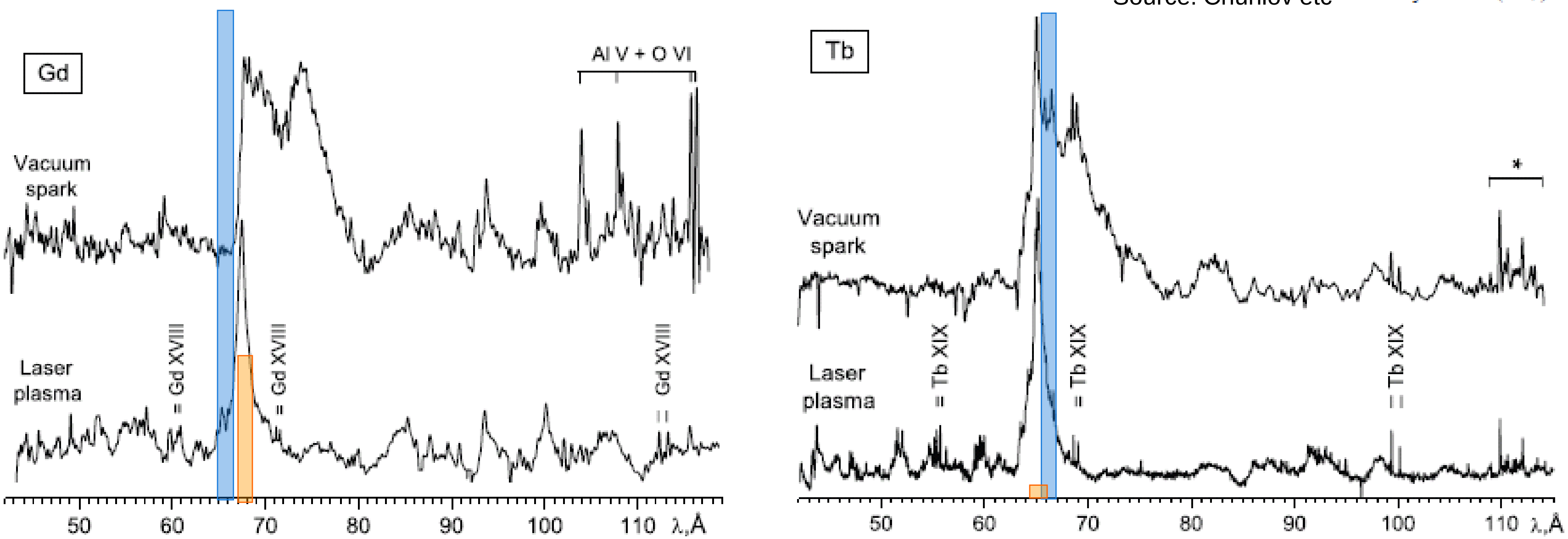
EUV and BEUV product roadmap spans >10 years

	0.25 NA		0.32 NA		*Under study* >0.40 NA	
Lens mirrors	6M	6M	6M	6M	6/8M	6/8M
Wavelength	13.5 nm	13.5 nm	13.5 nm	13.5 nm	13.5 nm	New λ
Product	**ADT**	**3100**	**3300B**	**3300C**	**3500**	**>3500**
Introduction year	**2006**	**2010**	**2012**	**2013**	**2016**	**>2018**
Resolution (hp)	32 nm	27 nm	22 nm	18 nm	11 nm	<8 nm
Sigma	0.5	0.8	0.2-0.9	OAI	flex OAI	flex OAI
Overlay (SMO)	7.0 nm	4.5 nm	3.5 nm	3.0 nm		
Throughput (wph)	4 wph	60 wph	125 wph	150 wph		

Possible new wavelength = 6.x nm

Source: materials and spectra

Source: Churilov etc Phys. Scr. 80 (2009)



- Optical throughput optimized for the coating (10 mirrors)
- Optical throughput optimized for the maximum emission spectrum

• Gd and Tb are the main potential materials of choice for 6.x lithography with the best shown CE in band of 1.8% (ISAN) (vs theoretical of 5%)
• Simultaneous optimization of ML band and emission spectral power is required
• Best achieved reflectivity of ML goes in the direction of 50% (vs 43% 1 year ago and theoretical ~80%) (Machotkin et al EUVL symposium, Miami)

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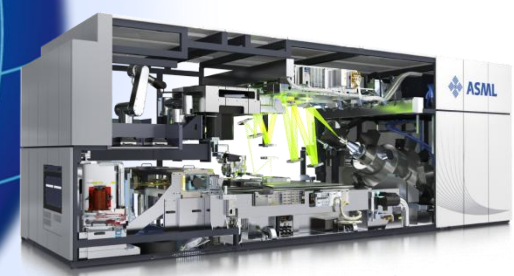
EUV has arrived worldwide in fabs

System 1
Exposing wafers for
device development

System 4:
Exposing wafers for
device development

System 2
Exposing wafers for
device development



System 5:
First customer
exposures done

System 3:
Exposing wafers for
device development

System 6:
Shipped

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Acknowledgements

The work presented today, is the result of hard work and dedication of teams at ASML and many technology partners worldwide including our customers

ASML is grateful for the support of the EAGLE and EXEPT projects, as well as the MEDEA+ and CATRENE organizations of the European Union